QWEST: Quantum Well Earth Science Testbed

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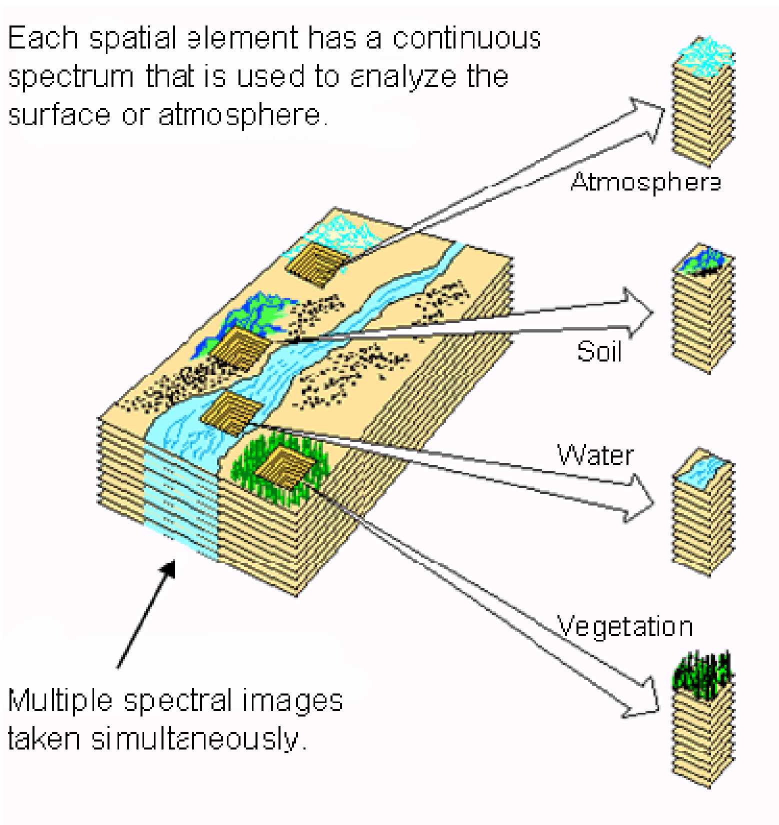
Outline

- Thermal Imaging Spectrometer for Earth Science
- Instrument Specifications
- Optical Design
- Components & Methodology
- First Light Testing & Results
- Summary

Thermal Imaging Spectroscopy for Earth Science



Volcanoes

What are the changes in the behavior of active volcanoes? Can we quantify the amount of material released into the atmosphere by volcanoes and estimate its impact on Earth's climate? How can we help predict and mitigate volcanic hazards?

Wildfires

What is the impact of global biomass burning on the terrestrial biosphere and atmosphere, and how is this impact changing over time?

Water Use and Availability

As global freshwater supplies become increasingly limited, how can we better characterize trends in local and regional water use and moisture availability to help conserve this critical resource?

Urbanization

How does urbanization affect the local, regional and global environment? Can we characterize this effect to help mitigate its impact on human health and welfare?

Land surface composition and change

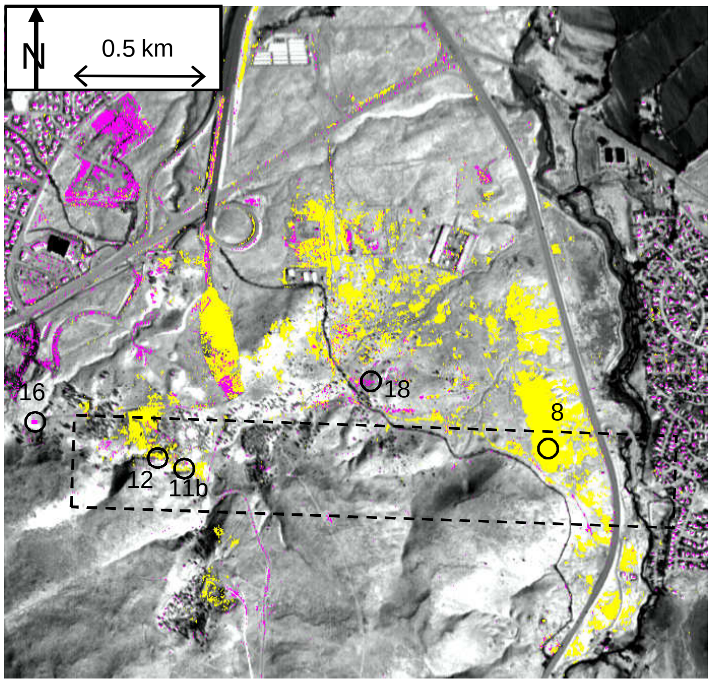
What is the composition and temperature of the exposed surface of the Earth? How do these factors change over time and affect land use and habitability?

Thermal spectroscopy acquires both the emission from the target source object as well as reflected and/or transmitted emission from surrounding and/or foreground objects.

Thermal Imaging Spectroscopy for Earth Science

MODIS/ASTER (MASTER) http://masterweb.jpl.nasa.gov/

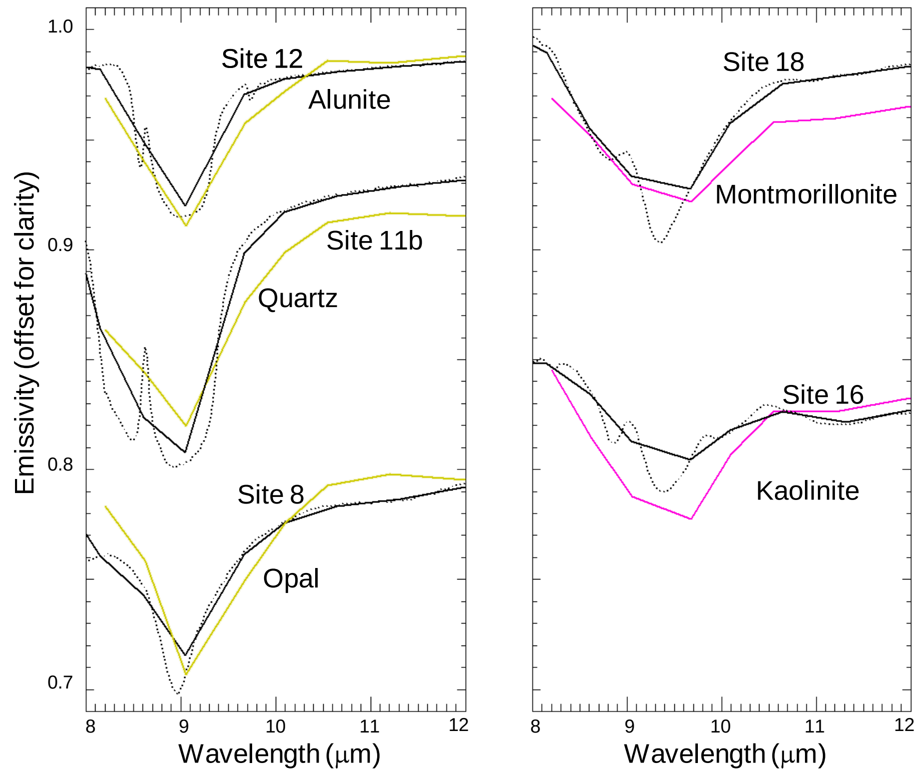
Steamboat Springs



Map Color Legend

Silica-rich (Opal, Quartz, Alunite)

Clay-rich (Kaolinite, Montmorillonite, Muscovite, Illite)



Emissivity plots derived from spectra

Instrument Specifications

HyTES (Hyperspectral thermal emission spectrometer) is an airborne sensor being developed under NASA's Instrument Incubator Program (IIP) in support of the HyspIRI mission. The HyspIRI mission is one of the 2nd tier missions recommends by the NRC Earth Science Decadal Survey. HyTES will have much higher spatial and spectral resolution than HyspIRI. HyTES will be used to determine the optimal spectral band placement for HyspIRI as well as develop HyspIRI algorithms and help prepare the scientific community for HyspIRI data. In preparation for HyTES we have developed a laboratory testbed instrument termed QWEST.

Instrument Characteristic	QWEST	HyTES
Number of pixels x track	320	512
Number of bands	256	256
Spectral Range	8-9 um (8-12um)	7.5-12 um
Integration time (1 scanline)	30 ms	30 ms
Total Field of View	40 degrees	50 degrees
Calibration (preflight)	Full aperture blackbody	Full aperture blackbody
QWIP Array Size	640x512	1024x512
QWIP Pitch *	25 um	19.5
QWIP Temperature	40K	40K
Spectrometer (Dyson) temperature	40K	100K
Slit Width	50 um	39 um
Pixel size at 2000 m flight altitude		3.64
Pixel size at 20,000 m flight altitude		36.4

Attributes of current QWEST instrument:

- Total system isolation form stray light past the spectrometer slit by cryogenically cooling all opto-mechanical structures to 40K.
- Single monolithic optics package with concave diffraction grating
- Minimize optics and focal plane array form factor by utilizing designs' inherent proximity with adequate thermal control (8hr operational)
- High throughput system design (F/1.6)

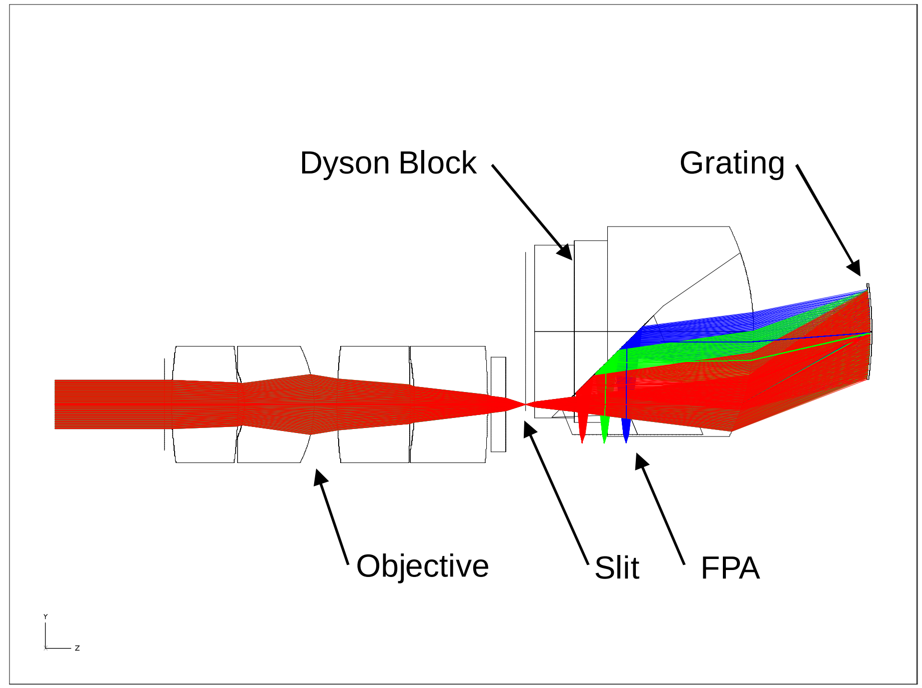
Optical Design

Dyson concentric design

Recent high fidelity pushbroom grating spectrometers typically use some form of the concentric Offner design.

This design is typically large with required F/#, fairly bulky & difficult to cool to cryogenic temperatures for the LWIR (i.e. 80K-90K).

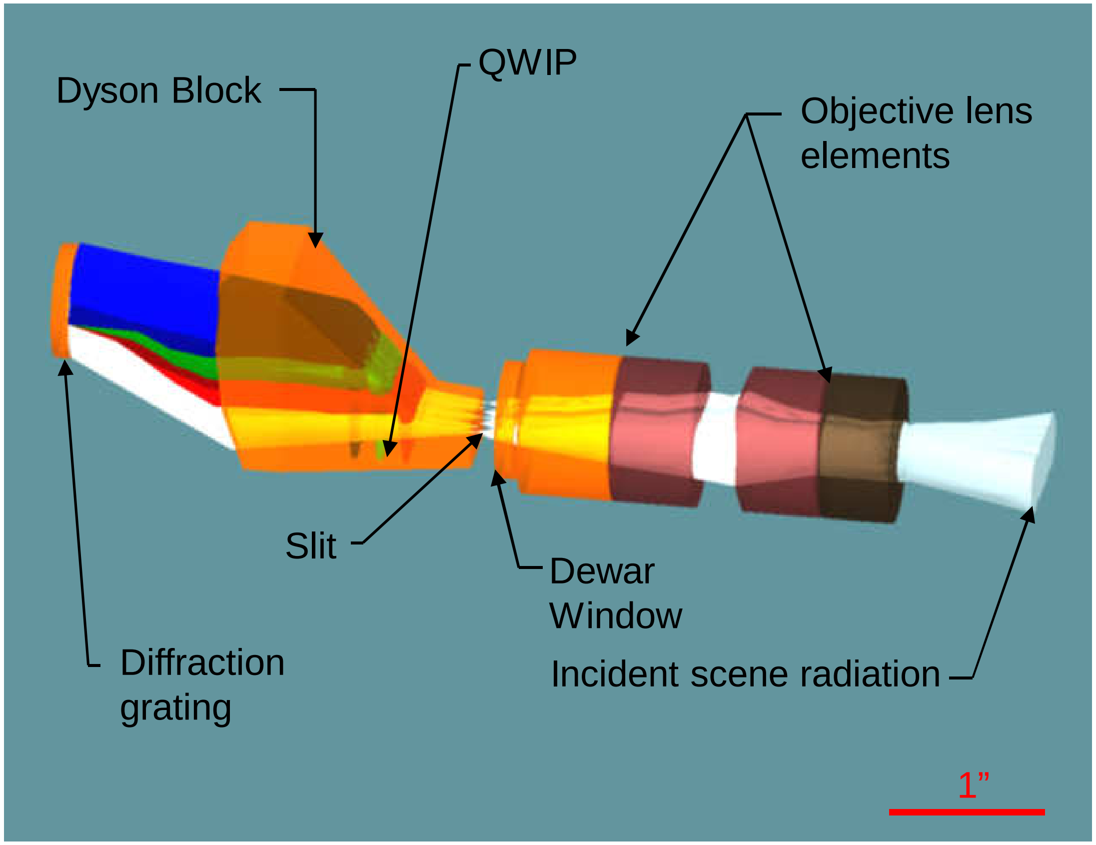
Dyson allows a miniaturized pushbroom thermal spectral imager at F/1.6 using only a single monolithic block and grating.



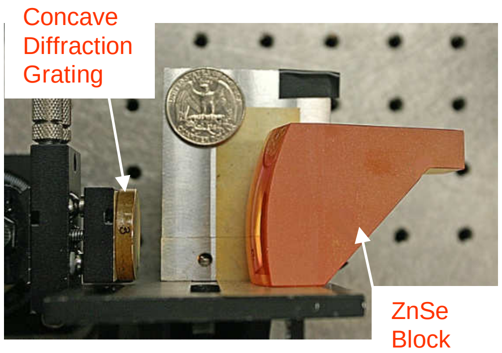
Basic design

Optimized for low ghosting and scatter

Optical Design



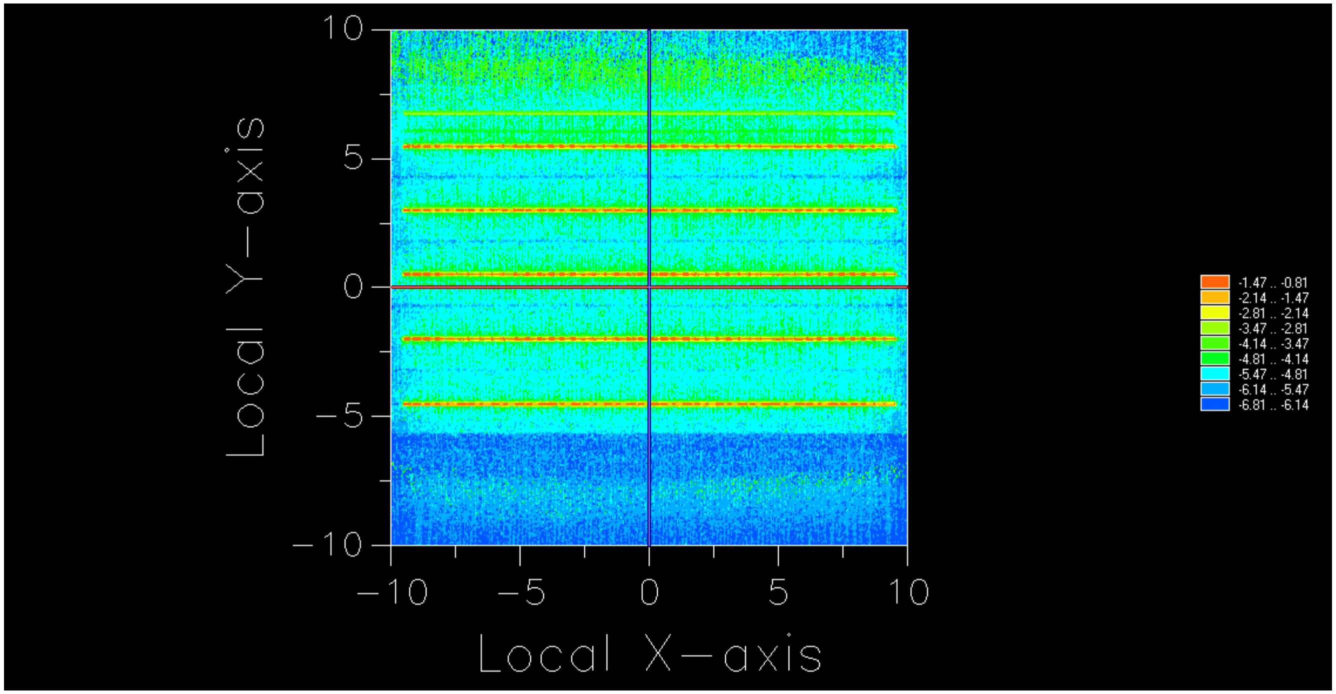
Modeling

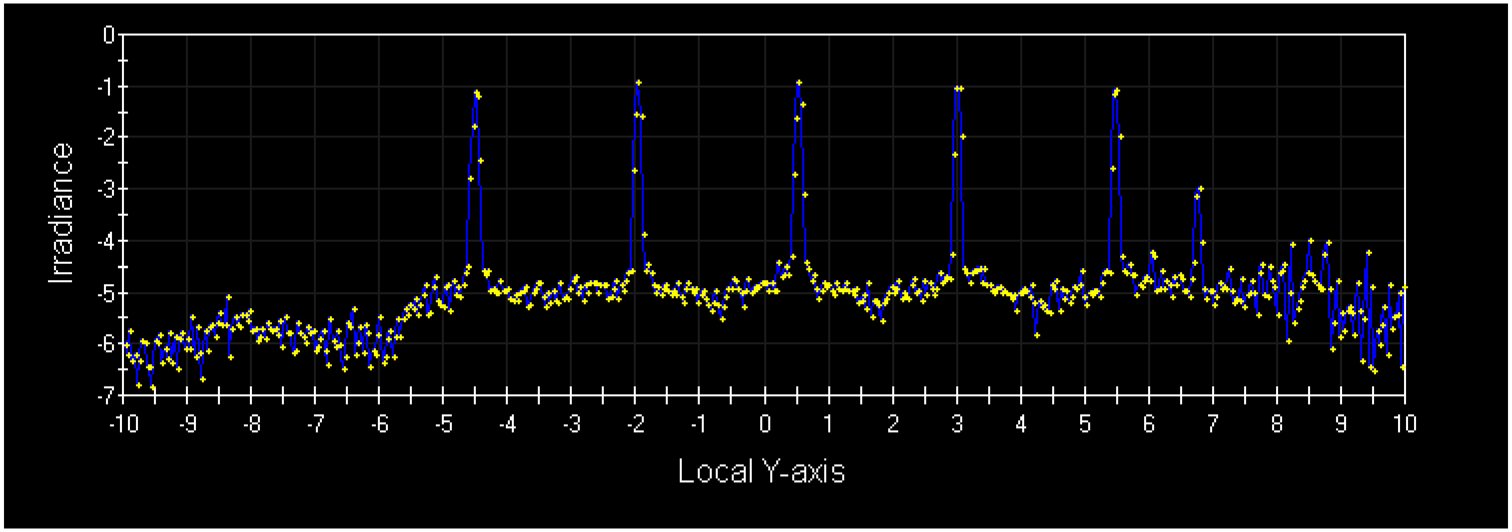


Complete LWIR Spectrometer Optics

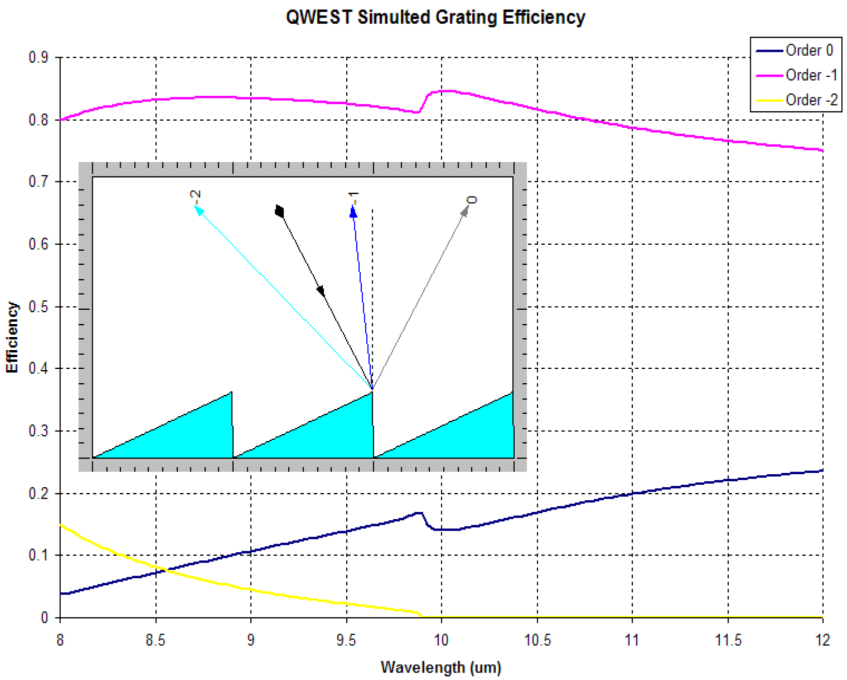
Laboratory Unit

Optical Design – Stray Light





Diffraction Grating

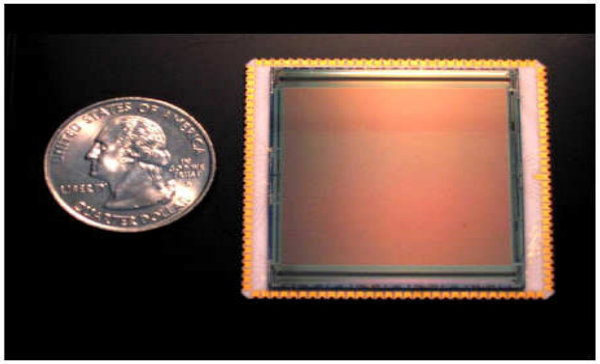


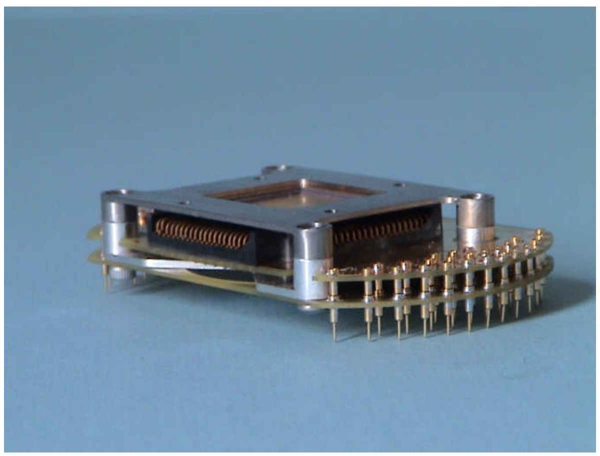
Blaze grating etched in PMMA on a concave surface using e-beam lithography. Blaze is coated with gold to maximize thermal reflectance. Gratings fabricated in this manner provide ultra-low scatter combined with high efficiency.

JPL developed calibration techniques allow writing on non-flat surfaces of height variation.

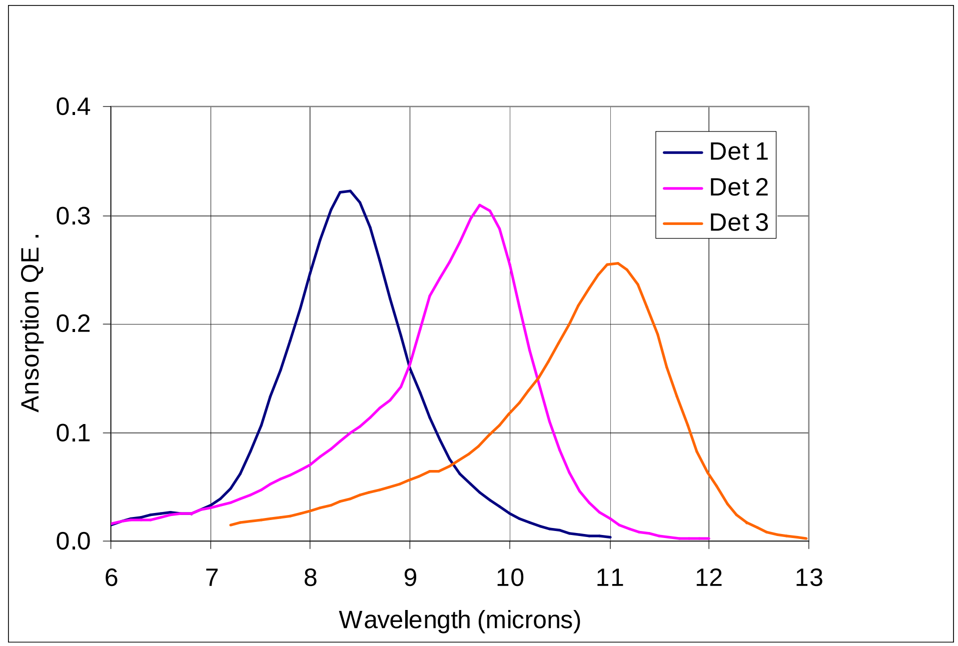
Daniel W. Wilson; Richard E. Muller; Pierre M. Echternach; Johan P. Backlund, "Electron-beam lithography for micro- and nano-optical applications," SPIE Proceedings Vol. 5720, January 2005.

Focal Plane Array





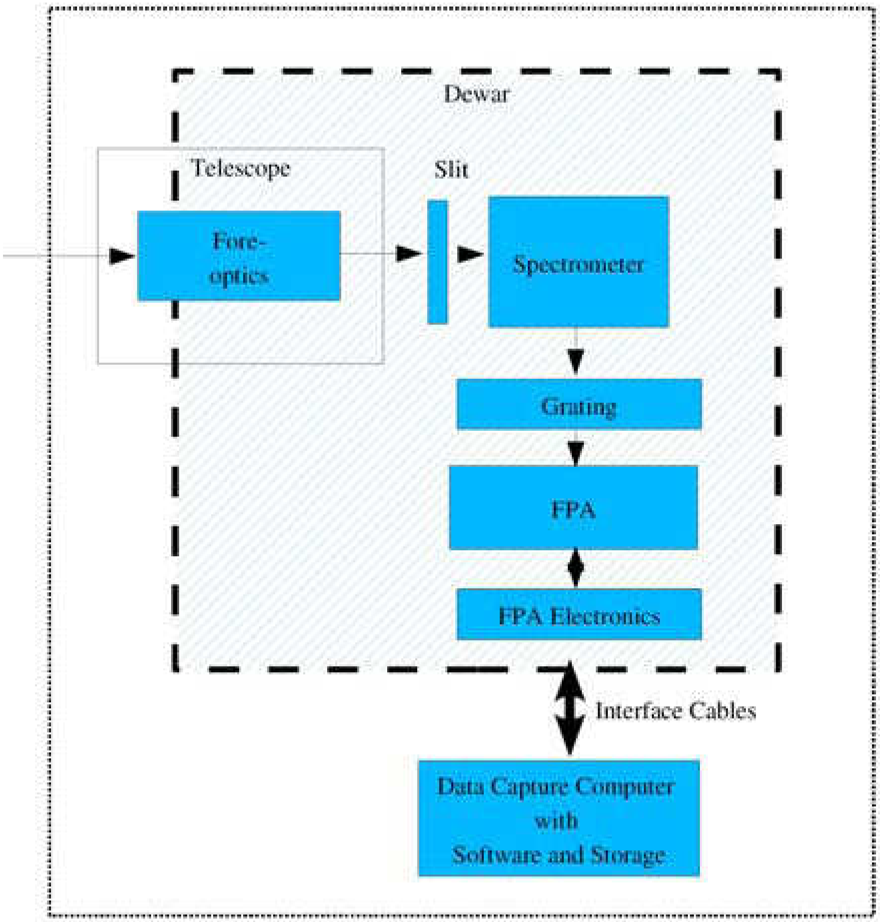
QWIP and Low-Profile Dyson mounting



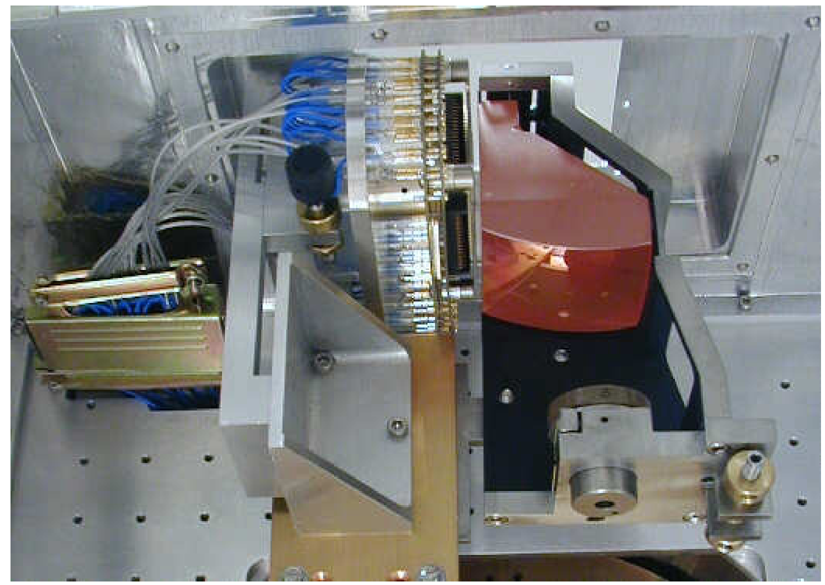
FPA Temperature Stability: +/-10mK at 40K

S. D. Gunapala, S. V. Bandara, J. K. Liu, S. B. Rafol, and J. M. Mumolo, "Large Format Multiband QWIP Focal Plane Arrays,"in Infrared Spaceborne Remote Sensing XI, Marija Strojnik, eds., Proc. of SPIE Vol. 5152, pp. 271-278, Nov. 2003.

System Layout



Model concept



Partially assembled
hardware in dewar

Traceable Standard Calibration

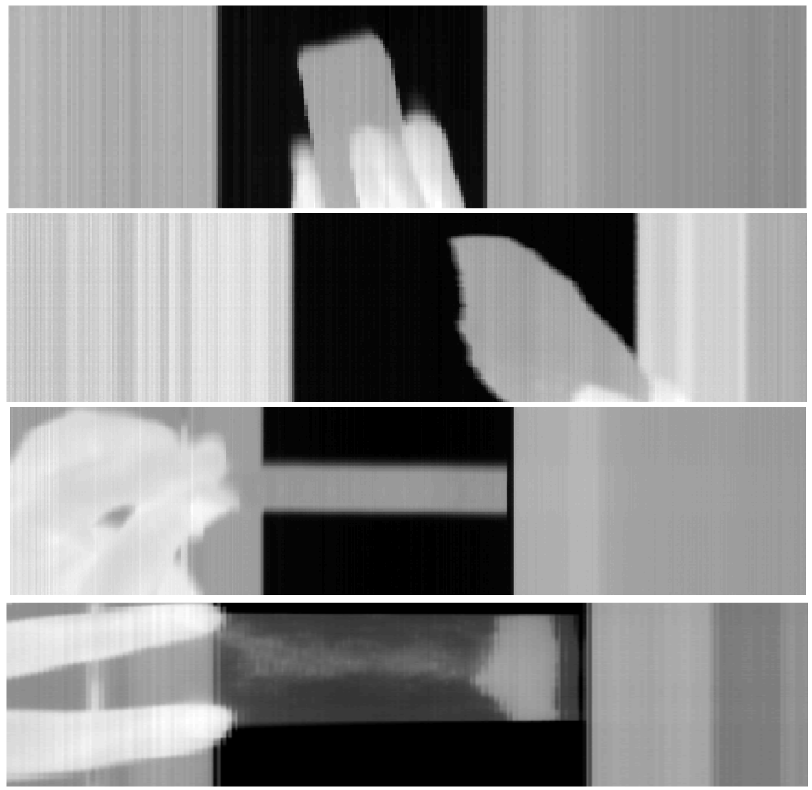
BB Assumed	35	30	25	20	15	10	5
Measure 1	34.8	29.88	24.98	20.07	15.21	10.06	5.04
Measure 2	34.75	29.93	24.97	20.08	15.18	10.06	5.05
Measure 3	34.77	29.89	24.99	20.08	15.15	10.06	5.1
Measure 4	34.81	29.88	24.98	20.07	15.18	10.08	5.14
Measure 5	34.79	29.88	24.99	20.08	15.14	10.06	5.12
avg	34.784	29.91	24.985	20.06333	15.14333	10.05333	5.075
std	0.024083	0.048166	0.010488	0.031411	0.074476	0.027325	0.053572
abs error	-0.216	-0.09	-0.015	0.063333	0.143333	0.053333	0.075

JPL has multiple NIST traceable blackbodies with a stability at 25 C of +/- 0.0007 C and a thermistor standard probe with an accuracy of 0.0015 °C over 0-60 ° C and stability/yr of 0.005

Calibration is performed in a ramp and soak mode where the blackbody temperature is increased by a set interval and allowed to soak for several minutes and then the temperature is measured.

We performed a transfer calibration on a Santa Barbara Electro-Optics blackbody target from 35C to 5C.

Pushbroom Scans



Room temperature spatial pushbroom scans
(320x76), 30ms integration.

Radiometrically Calibrated Data

$R_\lambda = a + bD_\lambda$

where D is the acquired scene information, R is the scene radiance and

$$a = \frac{R_h D_c - R_c D_h}{D_c - D_h}$$

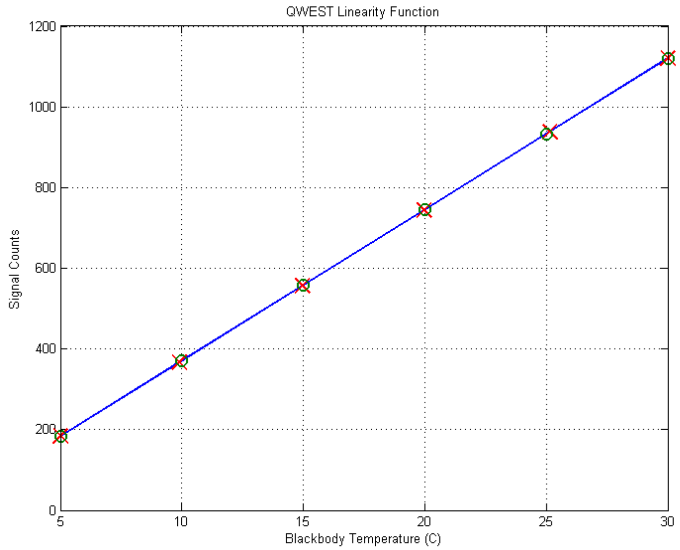
$$b = \frac{R_c - R_h}{D_c - D_h}$$

$$R_c = P(\lambda, T_c)$$

$$R_h = P(\lambda, T_h)$$

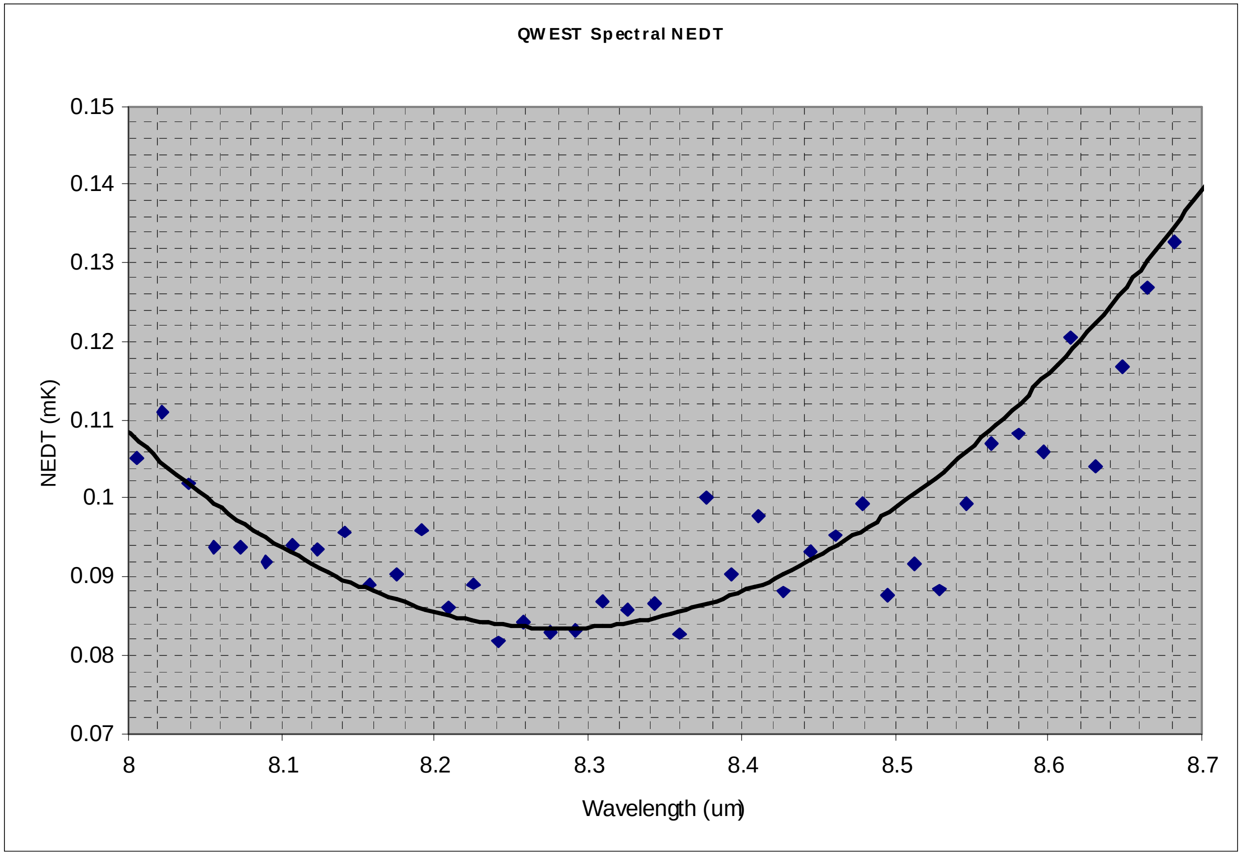
where the c and h subscripts imply cold and hot blackbody measuremetns respectively.

For emissivity, one simply assumes a temperature and divides out a Planck function from the radiance.



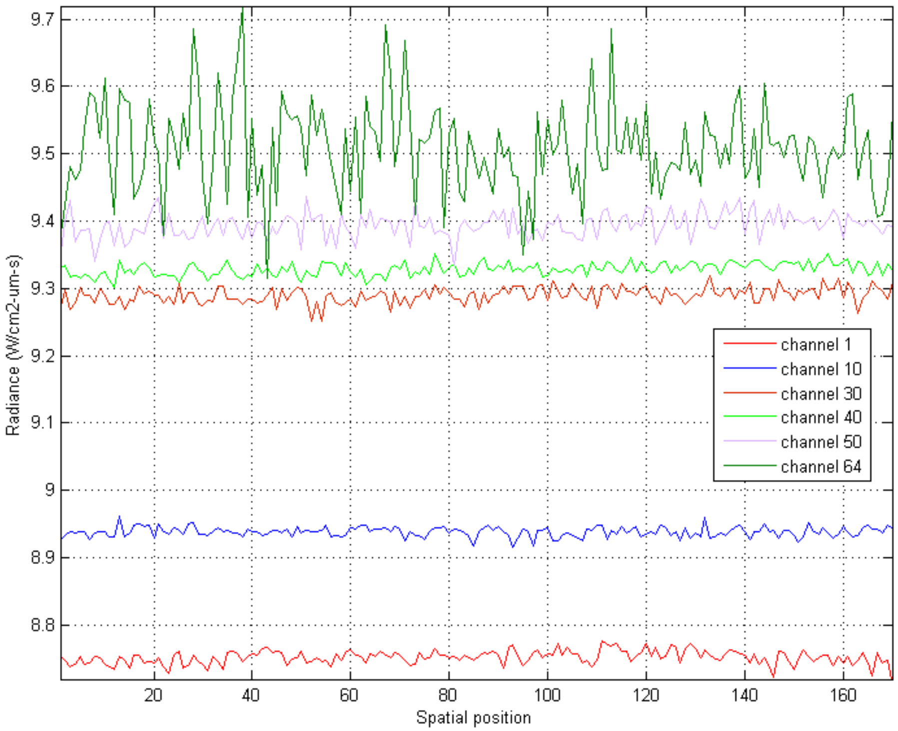
Actual T	Measured T	Abs. error T
5	5.00	0
10	9.90	-0.1044
15	14.96	-0.0445
20	19.98	-0.0213
25	25.14	0.1354
30	30.00	0

Radiometrically Calibrated Data



• Spectral Noise Equivalent delta Temperature (SNEΔT) is as expected for the given bands.

Radiometrically Calibrated Data



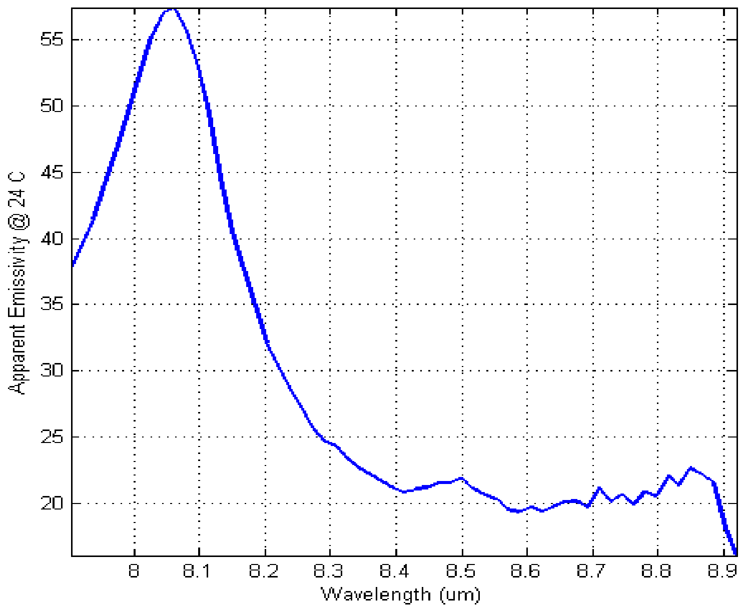
Excellent uniformity achieved across array

When radiance is converted to brightness temperature, one sigma error in uniformity is equal to +/-0.05C in temperature.

Limitations:

1) Flat blackbody calibrator (scene)
2) Background
3) QWIP Detector

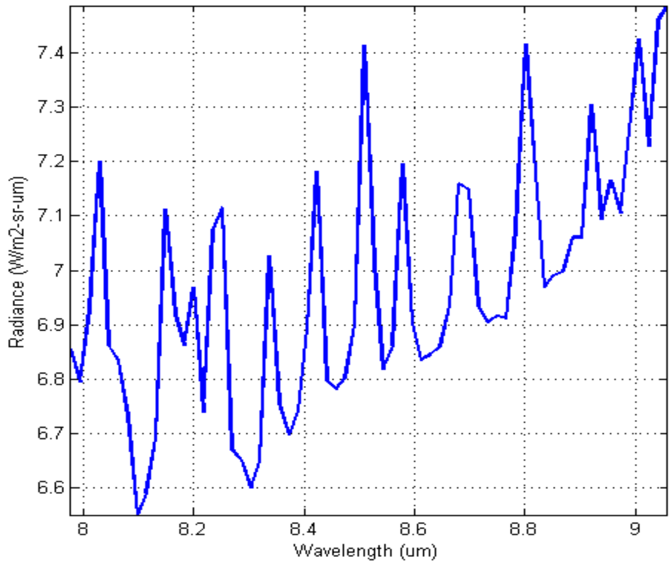
Radiometrically Calibrated Data



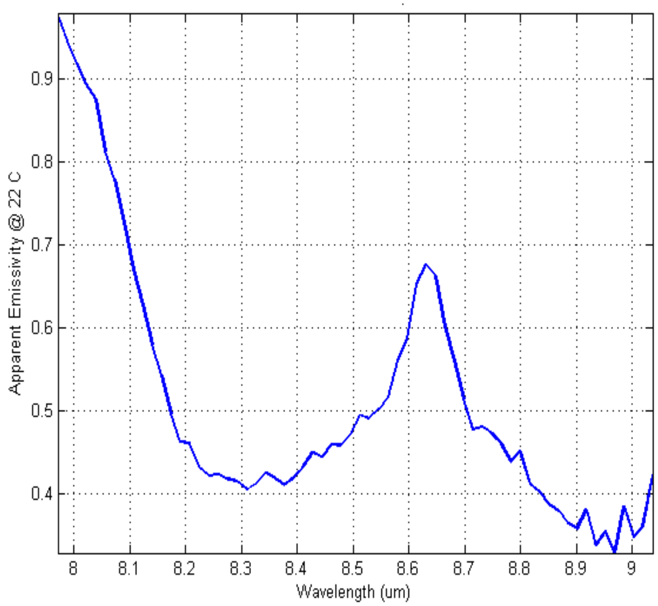
Emissivity spectra from miscellaneous polyurethane source.

Agrees well with independent point laboratory measurements made in transmission and reflection.

Radiometrically Calibrated Data



Radiance of gold standard with superimposed atmospheric bands as measured in direct sunlight. Agrees well with JPL's Aster spectral library.



Apparent emissivity of quartz as measured by QWEST in direct sunlight. Agrees well with JPL's Aster spectral library.

S. J. Hook, A. B. Kahle, "The Micro Fourier Transform Interferometer," Remote Sensing Environment, Elsevier Science, 56:172-181.

Summary & Conclusion

Summary

- We have presented a proof of concept vehicle which allowed the integration of a QWIP sensor with a Dyson spectrometer.
- Preliminary calibrated science results are promising.
- QWIP appears to be a valid technology for Earth Science applications (although the bandwidth is somewhat limited at the moment).
- We're approaching confirmation of spectral alignment to meet stringent earth science requirements.

Future work:

1. Install the broadband 8-12um QWIP focal plane array and continue fine alignment procedures.
2. Continue to perform field work to support HyspIRI-TIR.
3. Continue the transition from liquid cryo field instrument (QWEST) to mechanical cryocooler airborne instrument (HyTES).